SAND2020-2990C

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Sandia National Laboratories

Quantum Performance Assessment

Quantum Performance Lab @ Sandia National Laboratories

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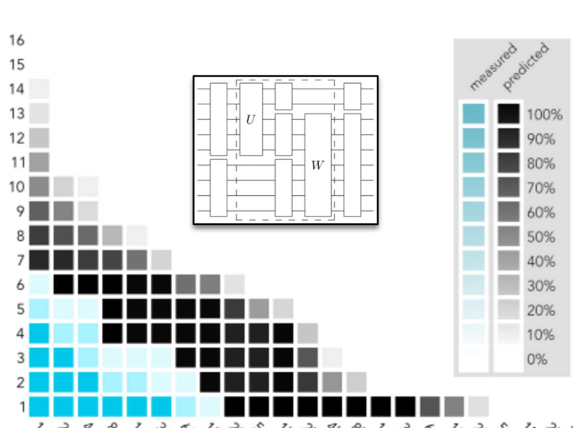
Our Mission at the *Quantum Performance Laboratory*

At Sandia's Quantum Performance Laboratory (QPL) we invent, develop, and improve techniques to evaluate as-built quantum information processors, and assess every aspect of their performance. These tools allow stakeholders — QC customers, funding agencies, DOE, the US Government, CEOs, VCs, etc — to understand a processor's performance, track progress, and make wise decisions.

Targeted Benchmarking of Holistic Performance

Whether a particular quantum processor is useful for a particularly task depends on what circuits it can run successfully — the processors's *capability*.

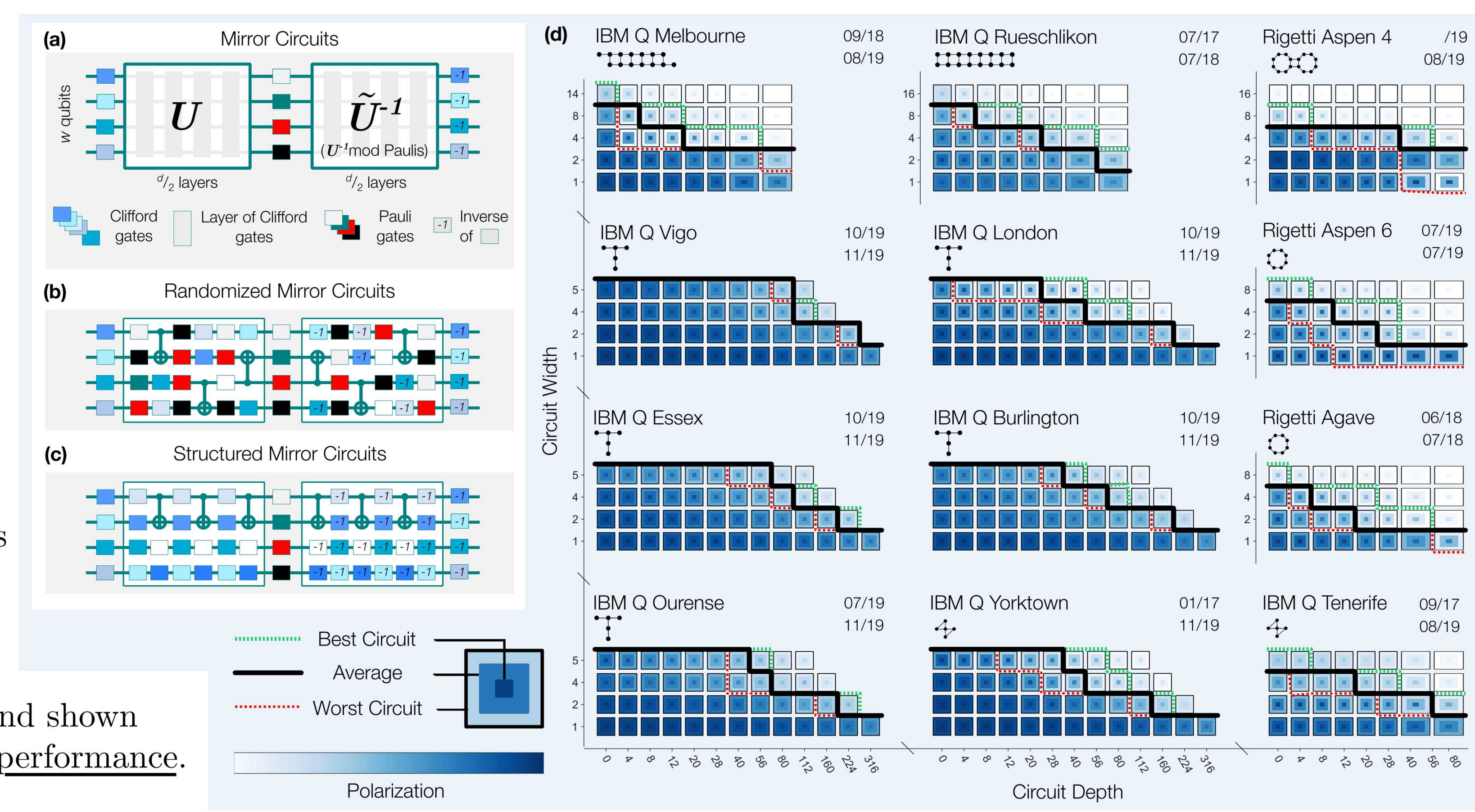
We can probe a processors's capability using carefully designed benchmarking circuits, and plot observed and predicted performance versus circuit width and depth.[1]



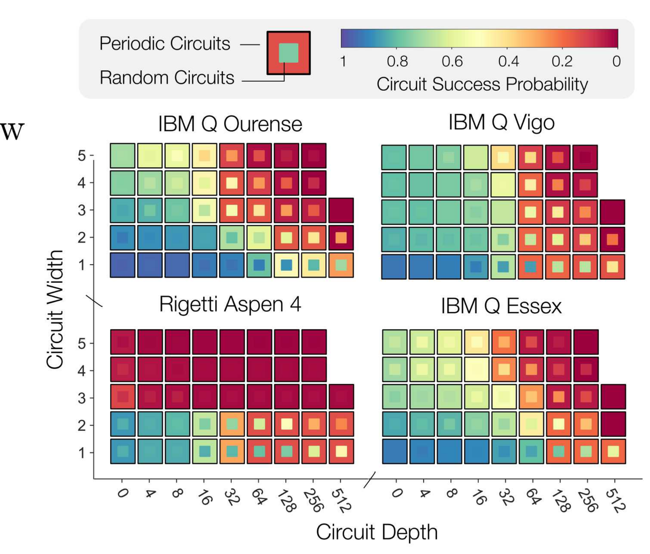
A user can then take *their* circuit, find its width and depth, and predict its performance using this plot.

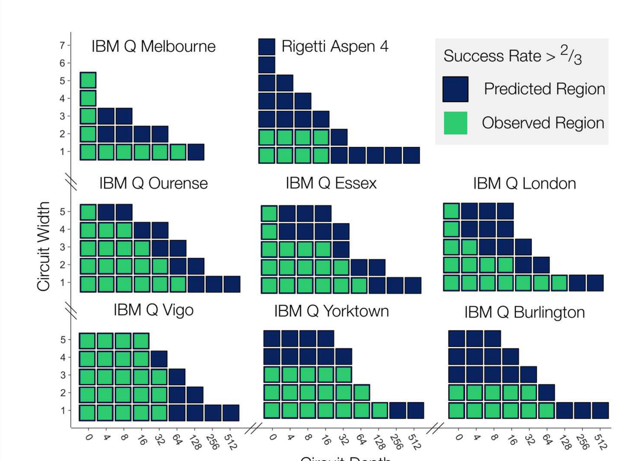
We've developed a class of circuits for targeted, scalable benchmarking: *mirror circuits*.[8]

Using these circuits we've benchmarked current hardware and shown that generic, randomized benchmarks are not predictive of performance.



Our experiments show that *periodic circuits* amplify errors that are suppressed in randomized circuits. Therefore targeted, algorithm-specific benchmarks are necessary.





We use the data from these benchmarks to estimate *capability regions*. If your circuit is within that region there's a good chance it'll run successfully! If not, you're pushing your luck!

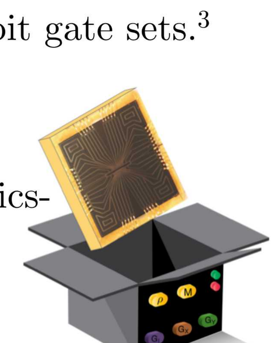
Low-Level Error Characterization

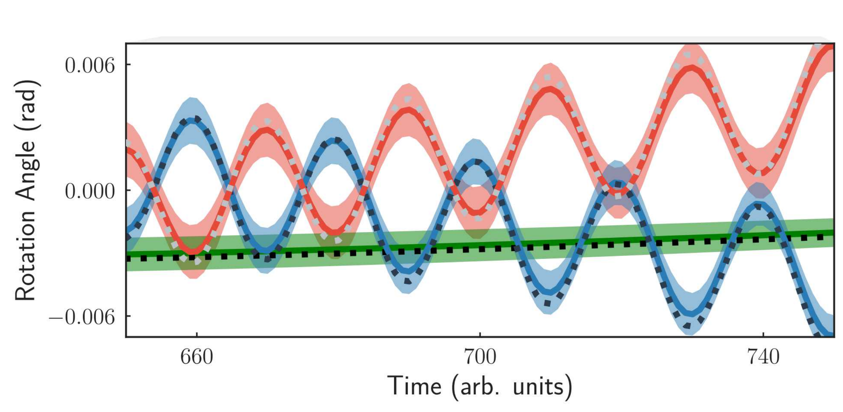
Comprehensive Characterization with GST

Gate set tomography (GST)[3] is the only tool for comprehensive, self-calibrating, and high-precision reconstruction of a full set of quantum logic gates. It is the cornerstone of our software `pyGSTi`.

GST was originally a tool for characterizing 1- or 2-qubit gate sets.[3] But we're also developing:

- *Many-qubit* GST, for characterizing 3-10 qubits.[8]
- *Custom-model* GST, which fits data to custom physics-inspired noise models.[8]
- *Measurement* GST, which characterizes gate sets containing mid-circuit measurements.[8]
- *Time-resolved* GST, which characterizes drifting gates.[4]





Tracking drifting gate rotation angles with TR-GST

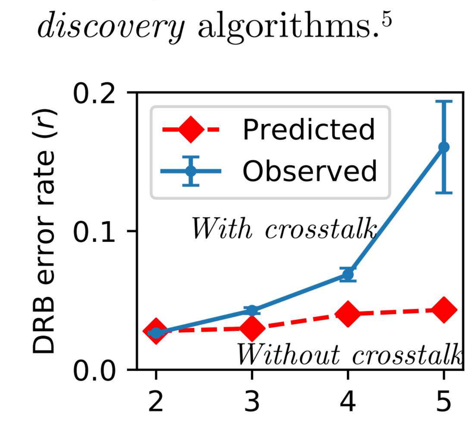
Some of these advanced methods are already available in `pyGSTi`. Come talk to us — or look at `pyGSTi`'s tutorials — if you're interested in using them!

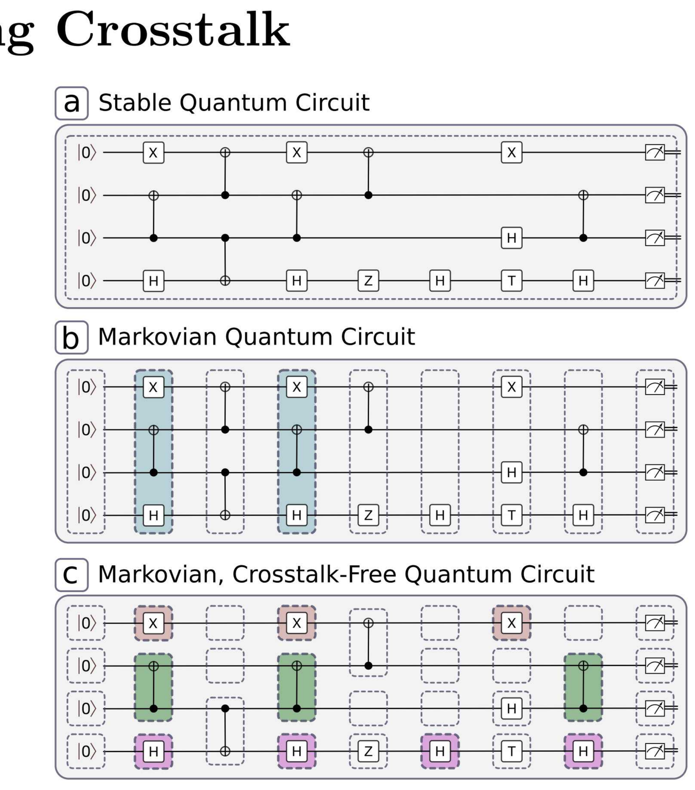
Measuring Crosstalk

Crosstalk is a class of potentially catastrophic errors, whereby errors are spatially correlated across qubits.

We've developed a comprehensive definition for crosstalk — as violations of *independence* and *locality* — and we've developed methods for measuring these errors:

- An efficient crosstalk detection routine, based on *network discovery* algorithms.[5]



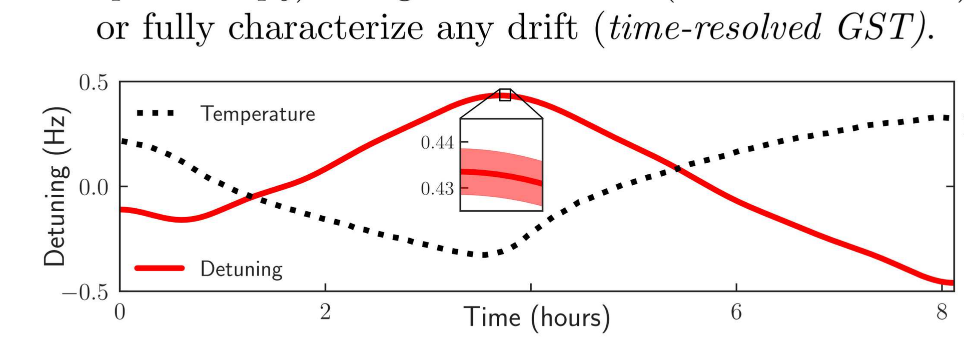


- *Idle tomography*, which is a scalable routine for characterizing "always-on" crosstalk.[8]
- Fast methods for roughly quantifying multi-qubit gate crosstalk using *direct randomized benchmarking*.[2]

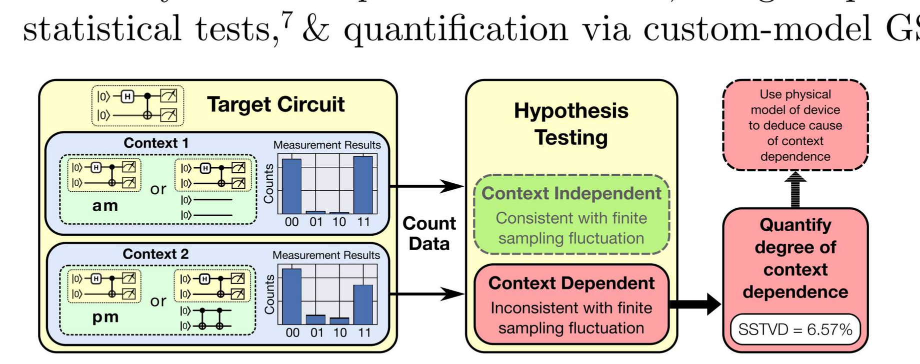
Diagnosing Drift & "Exotic" Errors

Quantum processors can be afflicted by all manner of complex "non-Markovian" errors. We're actively developing methods to measure these errors. These include:

- *Drift detection and quantification*[4] which can, e.g., track drifting magnetic fields (*time-resolved Ramsey spectroscopy*) and gate error rates (*time-resolved RB*), or fully characterize any drift (*time-resolved GST*).



- Arbitrary *context dependence* detection, using simple statistical tests,[7] & quantification via custom-model GST.



Engagement!

Do you *design*, *make*, *use*, or *hope to obtain* quantum computing hardware? We want to work with you! We collaborate with many experimental and theoretical research groups across academia, industry, and government. Our goal is to serve the needs of quantum computing stakeholders — hardware designers and builders, potential sponsors and customers, and folks who design and run quantum algorithms. We're especially excited to engage with experimental groups and algorithms researchers, so look us up!

[1]Blume-Kohout & Young, arXiv:1904.05546 (2019), [2]Proctor *et al*, PRL 123 030503 (2019), [3]Blume-Kohout *et al.*, Nat. Commun. 8 14485 (2017), [4]Proctor *et al*, arXiv:1907.13608 (2019), [5]Sarovar *et al*, arXiv:1908.09855 (2019), [6]Nielsen *et al*, arXiv:2002.12476 (2020), [7]Rudinger *et al*, PRX 9 021045 (2019), [8]This is a currently unpublished method that's available in `pyGSTi` — take a look at `pyGSTi`'s tutorials or come talk to us!

PyGSTi

`PyGSTi` is the open-source software containing our methods. It is a mature Python package, providing powerful tools for simulation, tomography, benchmarking, data analysis, robust reporting and data visualization. It has extensive documentation and tutorials.

Originally an implementation of 1- and 2-qubit GST, pyGSTi can now be used to test 100s of qubits. It is constantly growing to implement our latest R&D and support the needs of the quantum hardware community.

`http://www.pygsti.info, arXiv:2002.12476 (2020)`

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